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Numerical Simulation of the Ground-Water Flow System of the Colville River Wastershed, Stevens County, Washington

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Introduction

In recent years, increased use of ground- and surface-water supplies in watersheds of Washington State has created concern that instream flows are insufficient for fish passage and other uses. The Stevens County Conservation District (SCCD) and the Colville River Watershed Planning Unit (Planning Unit) are working to develop a long-range sustainable watershed plan to meet the needs of current and future water demands within the watershed, while also working to protect and improve its natural resources. The USGS is currently working with the SCCD and Planning Unit to describe the geological framework of the wastershed. The ground-water flow system is not sufficiently understood at the watershed scale to effectively plan and manage the use of this resource.

Objectives

Building on our knowledge of the geological framework, USGS is attempting to model the ground-water flow system of the Colville River Watershed in order to effectively manage the water resources. Specific objectives of this modeling study are to:

- ✔ Determine the hydraulic properties of the major hydrogeologic units;
- ✔ Define and describe the regional ground-water flow system in the unconsolidated deposits; and
- ✔ Determine the effects of different ground-water use scenarios on both the ground-water and surface-water systems.

Study Area

The Colville River watershed covers an area of 1,007 square miles in northeastern Washington (fig. 1). The Colville River flows 43 miles in a southerly direction and empties into Franklin D. Roosevelt Lake (FDR Lake) on the Columbia River.

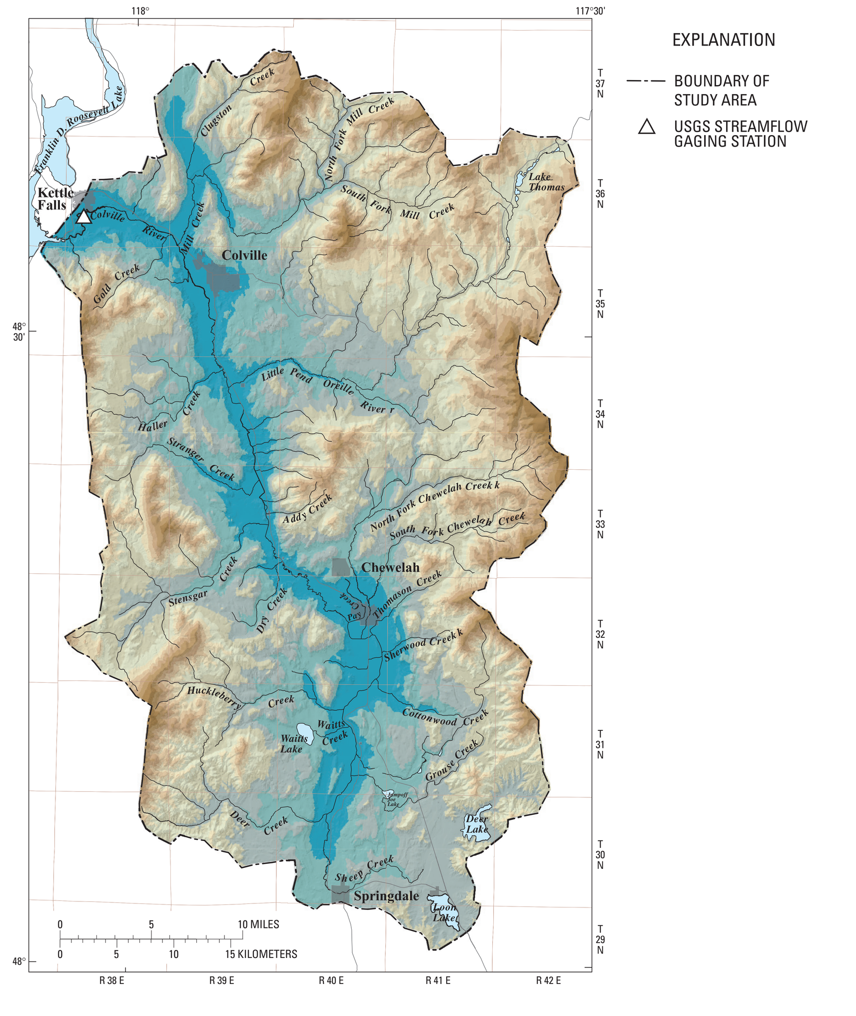

Figure1. Shaped relief map showing Colville Watershed and continuous-record gaging-station location.

Hydrogeology

Previous studies identified seven hydrogeologic units in the Colville River Watershed: Upper outwash aquifer (UA); Till confining unit (TC); Older outwash aquifer (OA); Colville Valley confining unit (VC); Lower Aquifer (LA); Lower confining unit (LC); and bedrock (BR) (S.C. Kahle, USGS; written communication, April, 2003). The hydraulic and geologic properties of each unit are shown in table 1.

Table 1. Summary of hydrologic and lithologic characteristics and estimated horizontal hydraulic conductivities of hydrogeologic units in the Colville River Watershed [--, not determined].

Hydrogeologic unit	Number of wells completed in unit	Hydraulic Conductivity (feet per day)			Range of thickness [estimated average thickness] (feet)	Lithology and hydrologic characteristics
		Minimum	Median	Maximum		
Upper outwash aquifer (UA)	114	1.9	84	2400	10 - 480 [100]	**Unconfined aquifer**. Consists of sand, gravel, cobbles, and silt with minor clay or till interbeds. Occurs in most stream valleys and terraces tributary to the Colville River.
Till confining unit (TC)	7	2.5	5.6	28*	4 - 250 [70]	**Low-permeability unit.** Consists of compacted and poorly sorted clay, silt, sand, gravel, and cobbles with locally occurring sand and gravel lenses.
Older outwash aquifer (OA)	13	--	270	--	2 - 56 [20]	**Discontinuous confined aquifer.** Consists mostly of sand and gravel underlying till and overlying bedrock. Occurs in tributary valleys.
Colville Valley confining unit (VC)	27	14	110	930*	1 - 570 [150]	**Low-permeability unit.** Consists mostly of glaciolacustrine silt and clay overlain in places by fine-grained alluvium. Occurs throughout the length of the Colville Valley and partway up some of the tributary valleys. Discontinuous lenses of aquifer material within the unit contribute usable quantities of water to some wells.
Lower aquifer (LA)	87	1.1	49	15,000	2 - 289 [60]	**Confined aquifer.** Consists mostly of sand, some gravel. Occurs in the Colville Valley beneath the VC Thickness and extent not known well.
Lower confining unit (LC)	0	--	--	--	1 - 454 [unknown]	**Low-permeability unit.** Consists mostly of glaciolacustrine silt and clay, includes till in places.
Bedrock (BR)	79	0.0011	1.3	4.4	--	Includes conglomerate, sandstone, siltstone, shale, quartzite, dolomite, argillite, granite and basalt. Locally yields water where rocks are fractured

*Hydraulic conductivity of coarse lenses within the unit

During the development of the geological framework, well log data from drillers' reports from over 300 field-inventoried were entered into Rockworks 2002. Cross sections were created in order to identify and correlate hydrogeologic units (fig. 2).

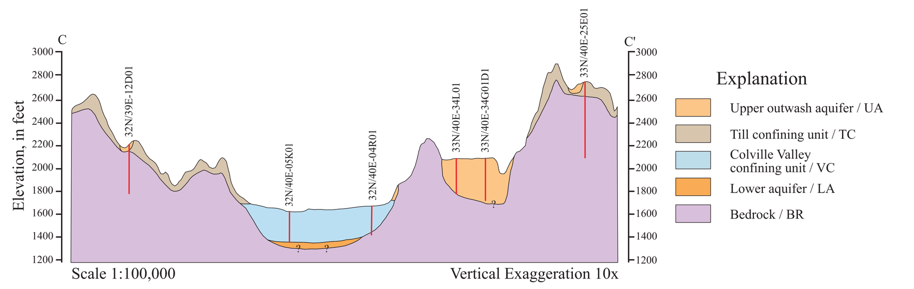

Figure 2. Example of a hydrogeologic cross section using Rockworks 2002.

Using Arc/Info GRID™ module, digital elevation surface grids were created for five units: UA, TC, VC, LA and the top of bedrock. Input point unit elevation data for UA and VC were used to create top and bottom surfaces with Arc/Info's TOPOGRID surface interpolator. The resulting digitally created stacked grid surface profiles (fig. 3) were compared to the cross sectional results of the previous hydrogeologic framework (fig.2).

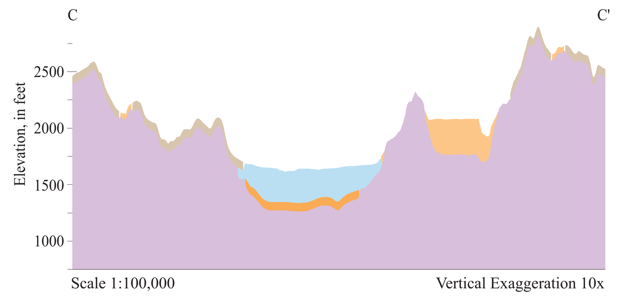

Figure 3. Example of digital hydrogeologic cross section created in Arc/Info GRID.

The horizontal extent of UA, VC, TC, LA and BR were also defined based on the interpretation of geologic cross sections generated in Rockworks 2002 (fig. 4). Extents and thicknesses were hand contoured onto base maps and digitized using Arc/Info. Separate coverages were created for each unit. These coverages were converted and imported into the modeling graphical user interface for Groundwater Modeling System (GMS).

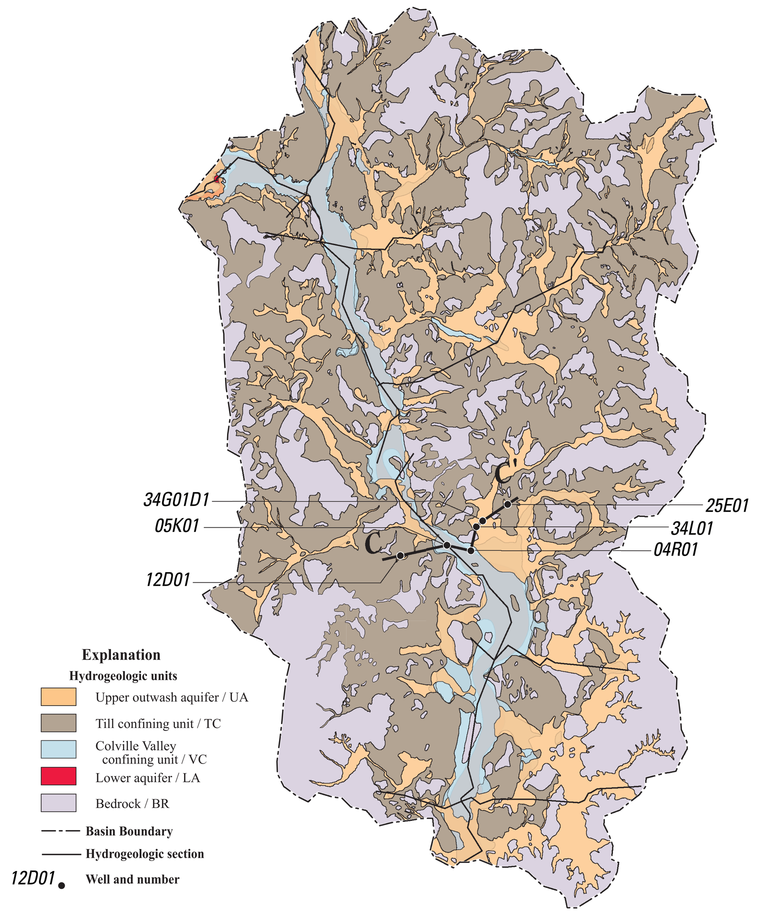

Figure 4. Surficial extent of hydrogeologic units of the Colville River Watershed (S.C. Kahle, USGS; written communication, 2003).

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Sources and Sinks

In addition to top elevation, bottom elevation, the areal extent and, hydraulic properties of each hydrogeologic unit, known sources of water (recharge) and sinks (rivers, lakes and pumping wells) are also required to model flow. Recharge was calculated using a surface-water modeling program called Precipitation Runoff Modeling System (PRMS). For each modeling runoff unit (MRU) defined in the Colville River Watershed, the program calculated a range of estimated recharge rates (fig. 5).

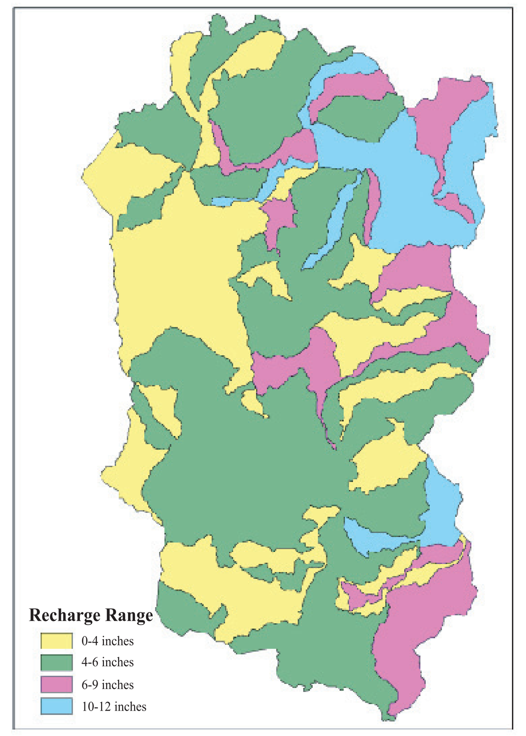
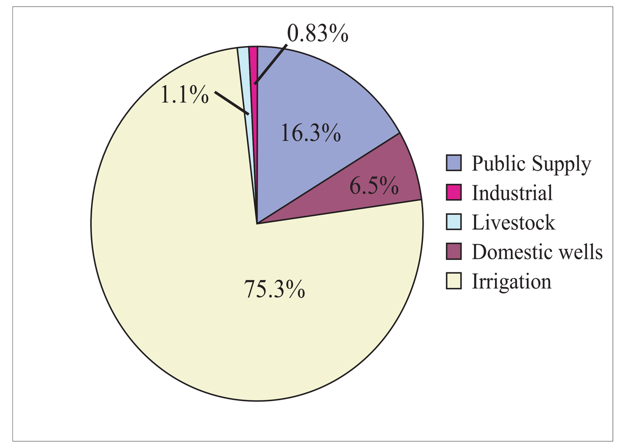


Figure 5. Recharge for MRUs in the Colville River Watershed calculated from PRMS.

Total surface-and ground-water withdrawals during 2001 were estimated to be 9,340 million gallons or 28,700 acre-feet, 35 percent of which is from ground water (Table 2).

Table 2. Water use categories and withdrawals for 2001, Colville River watershed, Stevens County, Washington (S.C. Kahle, written communication).

Water use category	Total for 2001 million gal/yr	acre-ft/yr
Public Supply	1,520	4,670
Domestic wells	610	1,870
Irrigation	7,030	21,600
Livestock	101	310
Industrial	78	239
Total	9,340	28,700



Identification of surface-water sinks that tap each hydrogeologic unit were made by combining information on the locations of rivers and lakes with the coverages of surficial geology. The location of the screened interval of pumping wells determined the hydrogeologic unit in which wells were classified (fig. 6). Both the point coverage of pumping wells and the ARC coverage of river units were converted into shape files (.shp) and imported into GMS.

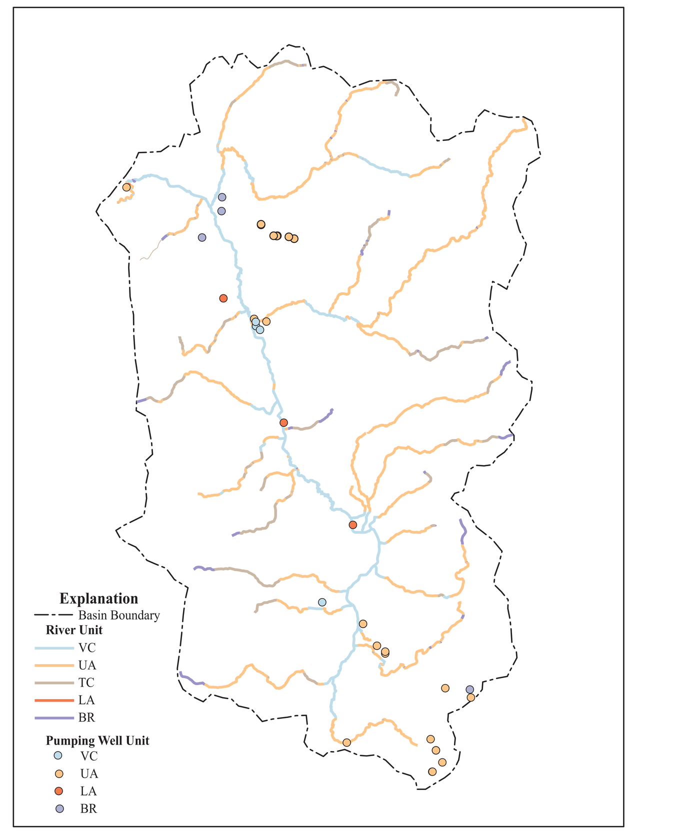


Figure 6. Hydrogeologic units of screened intervals of pumping wells and river segments.

Building the Model

Groundwater Modeling System (GMS) is a commercially available graphical user interface that uses the ground-water model MODFLOW-2000. MODFLOW-2000 is the latest version of a widely used three-dimensional, finite-difference model written by the U.S. Geological Survey (Harbaugh and others, 2000; McDonald and Harbough, 1988). This model version includes the Observation, Sensitivity, and Parameter estimation package (Hill and others, 2000) that uses nonlinear regression to refine the magnitude and distribution of key hydraulic parameters, as well as identify sensitivity parameters or subregions in the model domain where additional hydrogeologic information would improve the flow model.

Using GMS, a five-layer groundwater model was built with a 1500-foot grid scale. In the model, the base of the bedrock aquifer was set at 500 feet above sea level. Since previous studies suggest most water exits the watershed through the Lower Aquifer near Kettle Falls, drain cells were used in the model to simulate a sink at this boundary.

Preliminary Results

Preliminary model results indicate the model is stable with the parameters as developed. However, simulated water levels tend to be lower than water levels measured during 2002 water year (fig.7).

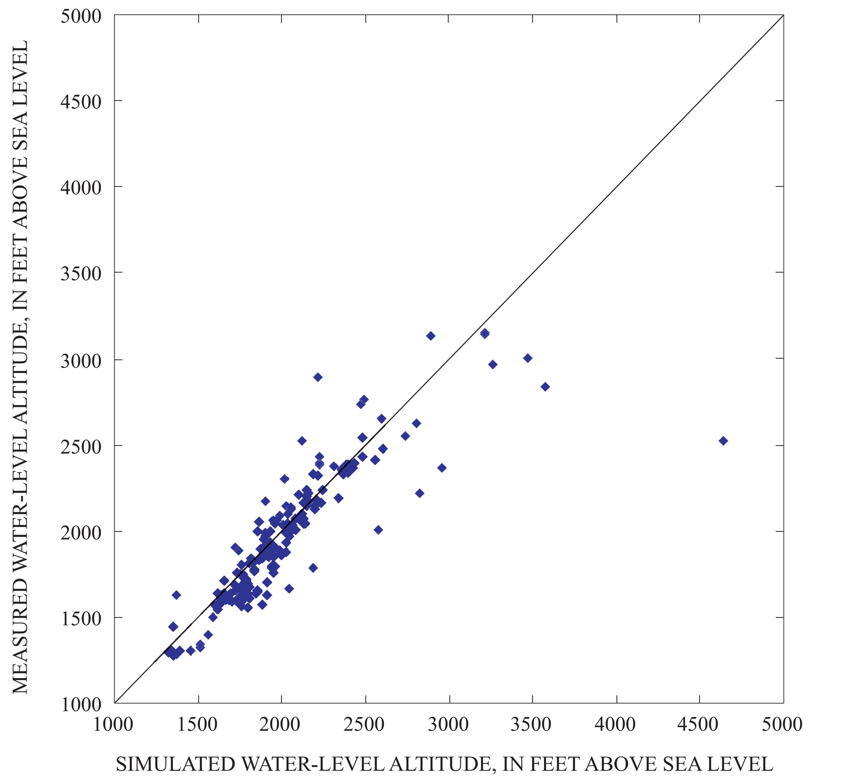


Figure 7. Linear regression of 2002 water levels in the Colville River Watershed of Stevens County, WA computed during initial groundwater model runs versus water levels measured during the 2002 water year.

Conclusions

The Colville River ground-water flow model will be calibrated to Water Year 2002 average-annual ground-water levels and stream flow discharge. Calibration of the model will continue using non-linear regression techniques, which calculate statistics on many aspects of the hydrogeologic system. Once calibrated, water planners will be able to use this ground-water model to evaluate the impacts of different ground-water use scenarios on ground-water levels and surface-water discharge within the watershed.

References

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